Reprinted from the *Journal of Production Agriculture*
Volume 11, no. 4, Oct.–Dec. 1998
677 South Segoe Rd., Madison, WI 53711 USA

Snow Catch and Soil Water Recharge in Standing Sunflower Residue

David C. Nielsen

Research Question

Sunflower offers central Great Plains growers an opportunity to diversify from the traditional winter wheat-fallow production system. Low soil water amounts after sunflower harvest require soil water recharge. The objectives of this study were to measure the effects of differences in stalk height and population on changes in snow depth and soil water during the winter and spring following sunflower harvest under the typically variable winter precipitation conditions of the central Great Plains.

Literature Summary

Standing sunflower stalks have been shown to be effective at reducing wind speed near the soil surface. Approximately four snowstorms with significant drifting potential due to snowfall amount and wind speed occur per year in northeast Colorado. These drifting snow storms have the potential to interact with standing sunflower stalks to trap snow. Wheat residue has been shown to trap snow and increase soil water content over winter in Colorado, North Dakota, and Saskatchewan. Snow catch generally increases as wheat stubble height increases. Measurements in sunflower stalks in Saskatchewan and North Dakota showed snow depths ranging from 9 to 15 in., with melted water equivalent ranging from 2.8 to 3.5 in.

Study Description

Seven sites with sunflower residue near Akron, CO, were observed during the winters of 1992–1993, 1993–1994, and 1994–1995. Sunflower stalks were laid flat after harvest, or left standing at either 17 to 19 in. or 26 to 29 in. Stalk populations varied from 10 600 to 26 100/acre. Snow depths were measured in the plot area following snow events. Soil water content was measured using a neutron probe and time-domain reflectometry.

Applied Questions

Are standing sunflower stalks effective at increasing snow catch and overwinter soil water content?

For drifting storms, standing sunflower stalks can increase snow depth three to 10 times over areas with residues not standing, depending on the wind velocity associated with the snow storm and the silhouette factor of the standing stalks. The increased snow catch can result in increases in overwinter soil water content. For winters with approximately normal winter storm conditions for northeastern Colorado, producers could expect to see overwinter soil water increase by about 4 in. as the silhouette factor increases from 0 to 60 sq in./1600 sq in. (Fig. 1).

Recommendations

Producers should leave sunflower stalks standing as tall as possible after harvest to potentially increase snow catch and overwinter soil water storage.

Full scientific article from which this summary was written begins on page 476 of this issue.

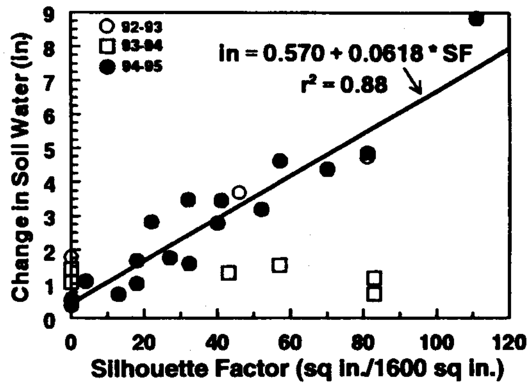

Fig. 1. Influence of sunflower silhouette factor on overwinter soil water change during three winters.

Snow Catch and Soil Water Recharge in Standing Sunflower Residue

David C. Nielsen*

Sunflower (*Helianthus annuus* L.) is an economically viable crop for dryland rotations in the central Great Plains. Sunflower's ability to extract large amounts of soil water can depress subsequent crop yields unless significant soil water recharge occurs. The objectives of this study were to measure the effects of differences in standing sunflower stalk height and population on snow deposition and subsequent overwinter soil water recharge. Observations of snow depth and overwinter soil water recharge were made at seven sites near Akron, CO, over three winters. Sunflower stalks were laid flat after harvest, or left standing at approximately 18 or 28 in. Stalk population varied from approximately 10 600 to 26 100/acre. Silhouette factor (stalk height × diameter × population) ranged from 0 to 111 sq in./1600 sq in. Soil types in the study areas were Rago silt loam (fine, smectitic, mesic Pachic Argiustoll) or Weld silt loam (fine, smectitic, mesic Aridic Paleustoll). Increasing stalk height (and silhouette factor) increased snow catch and soil water content during the winter, but amounts of increase varied depending on wind speed and snow amount. With near-average snowfall amounts and number of drifting storms, soil water recharged linearly with increasing silhouette factor, thereby increasing stored soil water by nearly 5 in. where silhouette factor was 80 sq in./1600 sq in. Maintaining standing sunflower residue during the winter and spring following sunflower harvest can provide critically needed soil water recharge by increasing depth of snow deposition.

SUNFLOWER is an agronomically viable crop for dryland rotations in the central Great Plains (Nielsen, 1998). But sunflower is a deep-rooted species capable of extracting large amounts of available water from deep in the soil profile (Jaafar et al., 1993; Jones, 1984; Hattendorf et al., 1988; Unger, 1990). Consequently, soil water contents are very low following sunflower production (Nielsen, 1997), requiring significant recharge prior to planting of the next crop in a rotation.

Northeast Colorado and other parts of the central Great Plains are in a unique position to take advantage of the snow-trapping capabilities of crop residues to augment the available water content of the soil (Greb, 1980). In this area, 73% of the total snow precipitation falls during nonfrozen soil conditions, resulting in low potential for runoff. Annual snowfall in northeast Colorado averages 24 to 42 in., with the gradient increasing from southeast to northwest. Greb (1980) also reported that Akron, CO, averages one blizzard per year (greater than 4 in. snow with 35 mph wind speed for at least 8 h). The presence of crop residues can extract a large quantity of snow from this type of storm. Storms of a less intense nature, but still with capacity to cause drifting and snow accumulation in crop residues happen about four times each winter (Table 1).

Bilbro and Fryrear (1994), reiterating the finding of Siddoway et al. (1965), stated that standing residue is more effective than flat residue for controlling wind erosion, because it absorbs more of the wind's energy and raises the zero-velocity-point above the soil. They also noted that the height, diameter, and number of stalks per unit ground area determine the effectiveness of standing residue, because these characteristics determine the silhouette area through which the wind must pass. Smika (1983) measured a 74% reduction in wind velocity at the soil surface when standing wheat (*Triticum aestivum* L.) stubble height was increased from 12 to 24 in. Nielsen and Hinkle (1994) reported a 33% reduction in wind speed at 8 in. above the soil surface when sunflower silhouette factor (stalk height × diameter × population) increased from 30 to 80 sq in./1600 sq in. Nielsen and Aiken (1998) found that increasing sunflower silhouette factor (through taller stalks or higher stalk population) reduced wind speed above and within standing sunflower stalks, thereby increasing the critical friction velocity ratio and reducing erosion ratio to less than 5% when silhouette factor was greater than 50 sq in./1600 sq in.

Reduction in wind speed within standing crop residue allows snow to drop out of the moving air stream. Steppuhn et al. (1986) reported snow measurements in standing sunflower stalks at two locations in Saskatchewan (18 in. tall stalks) and two locations in North Dakota (unspecified stalk height). Snow depths in the standing stalks ranged from 9 to 15 in., with the melted water equivalent ranging from 2.8 to 3.5 in. Caprio (1986) found 12 in. wheat stubble was approximately 30% more effective in harvesting snow for augmenting soil water than bare fallow in central Montana. Bauer and Tanaka (1986) in North Dakota reported that as wheat stubble height increased from 2 to 14 in., overwinter soil water recharge increased by 1.3 in., which they attributed to trapping of blowing snow. Smika et al. (1986) in Colorado showed no-till wheat stubble (unspecified height) averaged (over 11 winters) about 0.8 in. more overwinter soil water storage due to snow trapping than did plots that were conventionally tilled with a sweep plow after wheat harvest. Ries and Power (1981) noted that overwinter soil water storage in North Dakota increased 0.24 in. for each inch increase in wheat stubble height because of greater snow trapping.

Tabler and Schmidt (1986) suggested a relationship for estimating the maximum snow retention capacity (S) based on residue architecture as:

$$S = H - 0.01 \times A/D \quad [1]$$

Abbreviations:; A, soil surface area occupied by a stalk; D, stalk diameter; H, stalk height; S, maximum snow retention capacity.

USDA-ARS Central Great Plains Res. Stn., P.O. Box 400, Akron, CO 80720. *Corresponding author (dnielsen@lamar.colostate.edu).

Published in J. Prod. Agric. 11:476–480 (1998)

Table 1. Snowfall characteristics during three winters at Akron, CO.

Winter	Number of storms	Number of strong drifting storms†	Total snowfall	Total melted snow	Total winter precipitation‡
			in.		
1992–1993	16	4	34	3.93	4.62
1993–1994	10	1	24	3.02	4.66
1994–1995	16	4	44	4.16	5.12
Average§	12	4.3	32	3.82	4.05

† Strong drifting storm is defined as storm with wind gust greater than 25 mph with at least 1 in. of snow measured at the Central Great Plains Research Station weather station.

‡ First snow to last snow.

§ Averages are from 24 winters (1955–1956 through 1978–1979) at the Central Great Plains Research Station (Greb, 1980).

where

H = stalk height above the soil surface

A = soil surface occupied by a stalk = row spacing × distance between stalks within a row, and

D = stalk diameter

For stalks 29 in. tall and 1.06 in. in diameter planted in 30 in. rows and spaced 20 in. apart (10 450 stalks/acre), Eq. 1 estimates a maximum snow retention capacity of 23 in. A similar empirical relationship developed for typical wheat and barley (*Hordeum vulgare* L.) stem spacings was given by Steppuhn (1994) for predicting maximum snowcover retention capacity based on stubble height alone.

Campbell et al. (1992) observed an average of 1.6 times as much snow in tall (16–24 in.) as in short (6–8 in.) wheat stubble over 10 winters in Saskatchewan. However, they also noted that snow depths in tall stubble were not greater than in short stubble during winters with minimal snow accumulation. Greb (1980) showed overwinter precipitation storage efficiency in wheat stubble at Akron, CO, ranging from −94% to 85%, depending on winter storm conditions (snow amounts and wind speed). The average overwinter precipitation storage efficiency in wheat stubble was 55% (1959–1979).

Drifting snow causes sintering and abrasion of ice crystals into smaller particles, which pack into a denser state than undisturbed level snow (Greb, 1980). Over 24 winter seasons, Greb (1980) found drifted snow at Akron, CO to be 1.5 times more dense than adjacent level snow (19.8% vs. 13.1% water content).

The ability of sunflower residues of varying height and stalk populations to trap snow needs to be quantified under varying winter storm conditions, as well as the resultant changes in winter and spring soil water content to assess the soil and water conservation impacts of dryland sunflower grown in crop rotations in this region. The objectives of this study were to measure the effects of differences in standing sunflower stalk height and population (and, consequently, silhouette factor) on snow depth and soil water during the winter following sunflower harvest under the typically variable winter precipitation conditions of the central Great Plains.

MATERIALS AND METHODS

The study was conducted over three winters, with one observation site in 1992–1993, two sites in 1993–1994, and four sites in 1994–1995. The seven observation sites (Table 2) were located in existing sunflower fields at the Central Great Plains Research Station, 4 mi east of Akron, CO (sites

Table 2. Dimensions of sunflower residue and overwinter soil water change from seven sites near Akron, CO.

Site	Winter	Row direction	Stalk ht.	Stalk diam.	Population	Silhouette factor	Soil water measurement period	Soil water change†	Precipitation‡	Precipitation storage efficiency
			in.		stalks/acre	sq in./1600 sq in.		in.		%
1	1992–1993	E-W	29	0.87	12 600	81	18 Nov–30 Apr	4.74±0.98	4.15	114
			17	0.87	12 200	46		3.70±0.34	4.15	89
			flat	--	--	0		1.80±0.33	4.15	43
2	1993–1994	N-S	27	0.59	20 300	83	16 Nov–3 May	1.18±0.81	3.54	33
			18	0.55	17 000	43		1.33±0.12	3.54	38
			flat	--	--	0		1.04±0.59	3.54	29
3	1993–1994	N-S	29	1.06	10 600	83	16 Nov–3 May	0.70±0.16	3.54	20
			18	1.18	10 600	57		1.55±0.25	3.54	44
			flat	--	--	0		1.44±0.50	3.54	41
4	1994–1995	N-S	27	1.09	14 800	111	18 Nov–25 Apr	8.84±1.73	4.10	215
			19	1.10	15 100	81		4.86±0.75	4.10	119
			26	1.10	4 400	32		3.48±1.73	4.10	85
			flat	--	--	0		0.50±0.04	4.10	12
5	1994–1995	E-W	23	1.13	10 500	70	18 Nov–25 Apr	4.38±0.10	4.10	107
			17	1.14	8 000	40		2.79±1.07	4.10	68
			14	1.15	13 900	57		4.63±1.66	4.10	113
6	1994–1995	N-S	32	0.99	6 400	52	18 Nov–25 Apr	3.20±1.33	4.10	78
			31	0.91	5 700	41		3.46±0.87	4.10	84
			30	1.01	2 800	22		2.83±1.55	4.10	69
			29	0.84	2 900	18		1.02±0.89	4.10	25
7	1994–1995	N-S	18	0.80	7 400	27	18 Nov–25 Apr.	1.77±1.04	4.10	43
			25	0.80	3 500	18		1.68±0.29	4.10	41
			18	0.80	3 500	13		0.70±0.64	4.10	17
			19	0.80	900	4		1.08±0.27	4.10	26
			flat	--	--	0		0.39±0.31	4.10	10
			flat	--	--	0		0.56±0.23	4.10	14

† Average and standard deviation.

‡Amounts slightly different from total winter precipitation in Table 1 because soil water measurement period did not exactly correspond to first through last snow period.

3, 4, 6, 7), and in neighboring farmers' sunflower fields (sites 1, 2, 5). Soil types in the study areas were Rago silt loam or Weld silt loam. Row spacing was 30 in. at all sites. Stalk characteristics are given in Table 2. Plot size in all studies was 150 ft. by 150 ft., but plots were established in larger sunflower fields so that surrounding areas were in sunflower residue (about 18 in. tall) as well. Plant populations varied between sites, ranging from 900 to 20 300 stalks/acre. At harvest, stalks were cut at the desired height over the entire plot area, but generally were at either 17 to 19 in. or 26 to 29 in. Sites 1, 2, 3, 4, and 7 also had plots with stalks laid flat to the ground after sunflower harvest.

Following snowfall events, snow depths were measured at four locations near the center of each plot. Also at the center of the plot areas, soil water contents were measured with a neutron probe at depths of 18, 30, 41, 53, and 65 in., and by time-domain reflectometry in the 0 to 12 in. layer shortly after sunflower harvest in the fall, and again in the spring. Soil water content was measured in the fall and in the spring in four locations in each plot at sites 1, 3, 5, 6, and 7; and at two locations in each plot at sites 2 and 4. Water measurement locations were within 20 ft. of each other. Replicate measurements were averaged to give one reading per location. Precipitation storage efficiency was calculated as the ratio of measured overwinter soil water change to total overwinter precipitation (measured at the central Great Plains Research Station).

Stalk diameters were measured with a micrometer on 40 stalks in the center of each plot. The measurements were made 1.5 to 2.5 in. below the top of the stalk. A silhouette factor was calculated as the stalk diameter × the stalk height (both in inches) × the number of stalks in a 100 sq ft area (converted to number of stalks in a 40 in. by 40 in. ground area; Anonymous, 1994).

Standard deviation of replicate snow depths and soil water measurements were calculated. Linear regression was used to determine a relationship between silhouette factor and overwinter soil water change.

RESULTS AND DISCUSSION

A fairly wide range of silhouette factors (Table 2) was obtained during the study period (0 for areas with flattened stalks, up to 111 sq in./1600 sq in. for tall stalks at site 4). This range in silhouette factor caused differences in snow deposition, depending also on snowfall amounts and wind characteristics of individual storms. Characteristics of snowfall during the three winter seasons are given in Table 1.

The winter of 1992–1993 was very close to the average winter, while the winter of 1993–1994 was below normal in total snowfall and number of drifting snowstorms, and the winter of 1994–1995 was 38% above normal in total snowfall, 15% above normal in total melted snow, but normal in number of drifting storms.

The effect of stalk height and winter storm characteristics on snow depth is shown in Fig. 1. The winter at site 1 was one of nearly continuous snow cover from 21 Nov. 1992 through 15 Mar. 1993. On 11 Jan. 1993 the 27 to 29 in. standing stalks at site 1 had trapped more than three times the snow depth of the flat stalks. Reference wind speed (at 79 in. above the soil surface) during and after the snow event measured on 11 January averaged 15.8 mph with gusts up to 22 mph. Snow measurements made at sites 2 and 3 illustrate a different weather situation. During the entire winter of 1993–1994, only one snow storm with high wind speeds occurred, and there were no long periods of continuous snow cover. The reference wind speed during and after the snow event measured on 15 November averaged only 5.7 mph. But even with these low wind speeds, the ability of the standing stalks to trap more snow is seen. Reference wind speed during and after the snow storm of 27 Mar. 1995 (site 4) averaged 27 mph with gusts up to 36 mph. Very little snow stayed on the flattened stalk area. Over 9 in. of snow accumulated on the plots with tall stalks.

The large increase in snow catch at site 1 associated with the taller sunflower stalk height and greater silhouette factor resulted in significant increases in overwinter soil water storage (Table 2). Greater than 2.9 in. more soil water was stored under the tall standing stalks than in the soil where the stalks had been laid flat. Water use-yield relationships for this area of the central Great Plains (Nielsen and Halvorson, 1991; Nielsen, 1995) suggest that 2.9 in. of increased soil water (if it all could be retained in the soil profile until wheat planting) would result in an increase in wheat yield of about 18 bu/acre in a winter wheat-sunflower-fallow rotation. Because of the low snowfall amounts and only one drifting storm during the winter of 1993–1994 at sites 2 and 3, we saw no significant differences in change in soil water content due to stalk height and silhouette factor. Precipitation storage efficiency was lower during this winter, ranging from 20 to 44% in the standing residue. During the 1994–1995 winter (sites 4–7), locations with stalks laid flat showed only 0.39 to 0.56 in. increase in soil water, with overwinter precipitation storage efficiency of only 10 to 14%. In contrast, where the silhouette factor was 111 sq in./1600 sq in. (site 4), soil water increased by more than 8.5 in., for an overwinter precipitation storage efficiency of 215%.

The effect of silhouette factor on overwinter soil water recharge is seen more clearly in Fig. 2. For the two seasons with normal or somewhat above normal snow (1992–1993 and 1994–1995), soil water recharge increased linearly with increasing silhouette factor. During the low snowfall winter of 1993–1994, with only one drifting snow storm, there was no effect of silhouette factor on soil water recharge. For winters with conditions similar to 1992–1993 and 1994–1995,

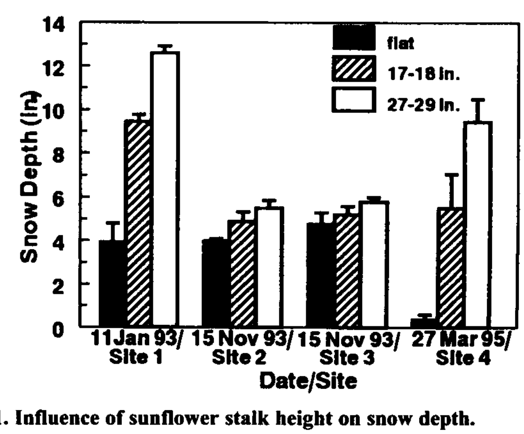

Fig. 1. Influence of sunflower stalk height on snow depth.

not greatly different from average, we might expect to see soil water increase by about 4 in. with a silhouette factor of 60 sq in./1600 sq in. For reference, a population of 14 000 stalks/acre with 1 in. diameter stalks 17 in. tall would have a silhouette factor of 60 sq in./1600 sq in.

Although limited, the soil water data shown in Table 2 and plotted in Fig. 1 do not indicate a difference in soil water recharge with row direction. This is consistent with the data and analysis presented by Nielsen and Aiken (1998), which showed only a 3 to 4% reduction in within-residue speeds of wind blowing perpendicular to row direction compared with wind blowing parallel to row direction. Even if there were a row direction effect on wind speed, it would probably not make a difference in snow accumulation because the winds during and after snowstorms in the central Great Plains generally blow at a 45° angle to row direction (i.e., northeast, northwest, southeast, southwest).

The maximum snow retention capacity, calculated from Eq. 1, is given in Table 3 for sites where snow depth measurements were made. The snow retention efficiency was calculated as the measured snow depth divided by the maximum snow retention capacity × 100. The minimum, maximum, and average values of snow retention efficiency are given in Table 3. Snow retention efficiency averaged less than 65% at all sites, indicating that weather (wind and snow) limited snow deposition, rather than lack of standing residue limiting snow deposition. In only two storms (one in 1992–1993 [Site 1] and one in 1994–1995 [Site 5]) did snow retention efficiency exceed 80%. This is in contrast to data from Canadian wheat and barley stubble fields that regularly fill to capacity with snow (Steppuhn, 1994). Because of lower snowfall amounts and frequent snow melting during winters in the central Great Plains, it is unlikely that snow depth would ever be limited by insufficient stalk height and population under normal after-harvest residue conditions. On the other hand, when diseases, insects, or mechanical action cause lodging of stalks after harvest, snow deposition will be limited by lack of sufficient residue, and not by lack of wind and snow.

Short stalks usually had higher snow retention efficiency than tall stalks. However, producers should be managing residues to maximize increases in overwinter soil water change and precipitation storage efficiency, which occur with high values of silhouette factor, generally as a result of tall stalks (Table 2).

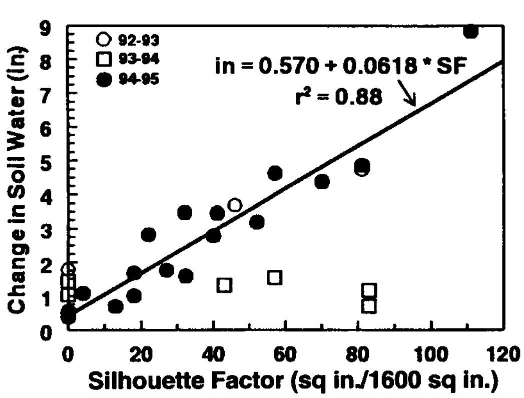

Fig. 2. Influence of sunflower silhouette factor on overwinter soil water change during three winters.

Table 3. Calculated maximum snow retention capacity and measured snow retention efficiency for five sunflower residue sites near Akron, CO.

Site	Stalk height	Snow retention capacity†	Snow retention efficiency: Minimum	Maximum	Average
	in.		%		
1	29	23	21	47	36
	17	11	32	86	63
2	27	22	18	30	24
	18	11	18	44	28
3	29	23	11	26	17
	18	13	12	38	25
4	27	23	15	31	25
	19	15	13	23	20
	26	13	24	41	31
5	23	18	6	40	17
	17	10	10	84	29

† From Eq. 1 (Tabler and Schmidt, 1986).

CONCLUSIONS

Standing sunflower stalks have great potential to trap snow and increase overwinter soil water content. This water is very important to the successful use of sunflower in dryland crop rotations in the central Great Plains because of the very dry soil profile following sunflower harvest. More snow is deposited in standing sunflower residue as the silhouette factor increases, either by increasing stalk height, stalk diameter, or stalk population. In the central Great Plains, the opportunities for recharging the soil profile by snow deposition in any type of crop residue increase from southeast to northwest due to an average annual snowfall gradient of 18 to 42 in. moving from southwest Kansas to the Nebraska panhandle (Greb, 1980). Amount of snow deposition will depend on both the amount of snow received during the winter and the wind speeds associated with winter storms.

ACKNOWLEDGMENTS

I express my appreciation to Steve Hinkle, Hubert Lagae, Gene Uhler, Bob Florian, Dee Webb, Kris Lindahl, Sharel Franke, Chad Kuntz, Dawn Scott, Karen Couch, and Mike Perry for assistance in plot preparation, data collection, and data analysis. I also express appreciation to Rick Lewton and Roger Ashley for the use of their sunflower fields, and to the National Sunflower Association for the generous financial support of this research.

REFERENCES

Anonymous. 1994. SCS training manual for Revised Wind Erosion Equation, RWEQ. USDA-ARS Wind Erosion and Water Conservation Research Unit, Big Spring, TX.

Bauer, A., and D. Tanaka. 1986. Stubble height effects on non-growing season water conservation. p. 255-272. *In* H. Steppuhn and W. Nicholaichuk (ed.) Proc. of the Symp. on Snow Management for Agric., Swift Current, Saskatchewan. July 1985. Great Plains Agric. Council Publ. no. 120. Univ. of Nebraska, Lincoln.

Bilbro, J.D., and D.W. Fryrear. 1994. Wind erosion losses as related to plant silhouette and soil cover. Agron. J. 86:550–553.

Campbell, C.A., B.G. McConkey, R.P. Zentner, F. Selles, and F.B. Dyck. 1992. Benefits of wheat stubble strips for conserving snow in southwestern Saskatchewan. J. Soil Water Conserv. 47:112–115.

Caprio, J.M. 1986. Potentials for harvesting water from snow. p. 109–131. *In* H. Steppuhn and W. Nicholaichuk (ed.) Proc. of the Symp. on Snow Management for Agric., Swift Current, Saskatchewan. July 1985. Great Plains Agric. Council Publ. no. 120. Univ. of Nebraska, Lincoln.

Greb, B.W. 1980. Snowfall and its potential management in the semiarid central Great Plains. USDA-SEA Agric. Rev. and Man. ARM-W-18. U.S. Gov. Print. Office, Washington, DC.

Hattendorf, M.J., M.S. Redelfs, B. Amos, L.R. Stone, and R.E. Gwin, Jr. 1988. Comparative water use characteristics of six row crops. Agron. J. 80:80–85.

Jaafar, M.N., L.R. Stone, and D.E. Goodrum. 1993. Rooting depth and dry matter development of sunflower. Agron. J. 85:281–286.

Jones, O.R. 1984. Yield, water-use efficiency, and oil concentration and quality of dryland sunflower grown in the southern High Plains. Agron. J. 76:229–235.

Nielsen, D.C. 1995. Water use/yield relationships for central Great Plains crops. Conservation Tillage Fact Sheet no. 2-95. Central Great Plains Res. Stn., Akron, CO.

Nielsen, D.C. 1997. Water use and rooting differences among various crops. p. 37–40. *In* R.L. Anderson (ed.) Proc. Ninth Annu. Conf. of the Colorado Conservation Tillage Assoc., Sterling, CO. 4–5 Feb. 1997. Colorado Conservation Tillage Assoc., Ault, CO.

Nielsen, D.C. 1998. Comparison of three alternative oilseed crops for the central Great Plains. J. Prod. Agric. 11:336–341.

Nielsen, D.C., and R.M. Aiken. 1998. Wind speed above and within sunflower stalks varying in height and population. J. Soil Water Conserv. 53:347–352.

Nielsen, D.C., and A.D. Halvorson. 1991. Nitrogen fertility influence on water stress and yield of winter wheat. Agron. J. 83:1065–1070.

Nielsen, D.C., and S.E. Hinkle. 1994. Wind velocity, snow, and soil water measurements in sunflower residues. p. 93–100. *In* D.J. Lyon (ed.) A future using residue management. Proc. Great Plains Residue Management Conf., Amarillo, TX. 15–17 Aug. Great Plains Agric. Council Bull. no. 150., Univ. of Nebraska, Lincoln.

Reis, R.F., and J.F. Power. 1981. Increased soil water storage and herbage production from snow catch in North Dakota. J. Range Manage. 34:359–362.

Siddoway, F.H., W.S. Chepil, and D.V. Armbrust. 1965. Effect of kind, amount, and placement of residue on wind erosion control. Trans. ASAE 8:327–331.

Smika, D.E. 1983. Soil water changes as related to position of wheat straw mulch on the soil surface. Soil Sci. Soc. Am. J. 47:988–991.

Smika, D.E., A.B. Page, and R.H. Mickelson. 1986. Snow water management for crop production in the central Great Plains. p. 335–344. *In* H. Steppuhn and W. Nicholaichuk (ed.) Proc. of the Symp. on Snow Management for Agric., Swift Current, Saskatchewan. July 1985. Great Plains Agric. Council Publ. no. 120. Univ. of Nebraska, Lincoln.

Steppuhn, H. 1994. Snowcover retention capacities for direct-combined wheat and barley stubble in windy environments. Canadian Agric. Eng. 36:215–223.

Steppuhn, H., D. Erickson, R.P. Zentner, and W. Nicholaichuk. 1986. Benefit/cost ratios for snow management techniques in semiarid climates. p. 613–656. *In* H. Steppuhn and W. Nicholaichuk (ed.) Proc. of the Symp. on Snow Management for Agric., Swift Current, Saskatchewan. July 1985. Great Plains Agric. Council Publ. no. 120. Univ. of Nebraska, Lincoln.

Tabler, R.D., and R.S. Schmidt. 1986. Snow erosion, transport, and deposition in relation to agriculture. p. 11–58. *In* H. Steppuhn and W. Nicholaichuk (ed.) Proc. of the Symp. on Snow Management for Agric., Swift Current, Saskatchewan. July 1985. Great Plains Agric. Council Publ. no. 120. Univ. of Nebraska, Lincoln.

Unger, P.W. 1990. Sunflower. p. 775–794. *In* B.A. Stewart and D.R. Nielsen (ed.) Irrigation of agricultural crops. Agronomy monogr. 30. ASA, CSSA, and SSSA, Madison, WI.